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(45) **Date of Patent: May 3, 2016**

(54) **OPTICAL REFLECTING ELEMENT AND ACTUATOR**

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G02B 26/08 (2006.01)
H04N 1/113 (2006.01)

(52) **U.S. Cl.**
CPC ***G02B 26/105*** (2013.01); ***G02B 26/0858*** (2013.01); ***G02B 26/101*** (2013.01); *H04N 1/113* (2013.01)

(58) **Field of Classification Search**
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USPC 359/196.1, 198.1, 199.1, 199.2, 213.1, 359/224.1, 221.2
See application file for complete search history.

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Primary Examiner — Darryl J Collins
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(74) *Attorney, Agent, or Firm* — McDermott Will & Emery LLP

(57) **ABSTRACT**

An optical reflecting device includes a movable plate having a reflecting surface, a first support portion, a first drive part, a first frame, and a monitor part for detecting the rotation of the movable plate. The first support portion is connected to the movable plate. The first drive part is formed in the first support portion and rotates the movable plate about a first axis. The first frame contains the movable plate and the first support portion, and is connected to the first support portion. The monitor part extends from that portion of the outer periphery of the movable plate which is most distant from the first axis.

13 Claims, 7 Drawing Sheets

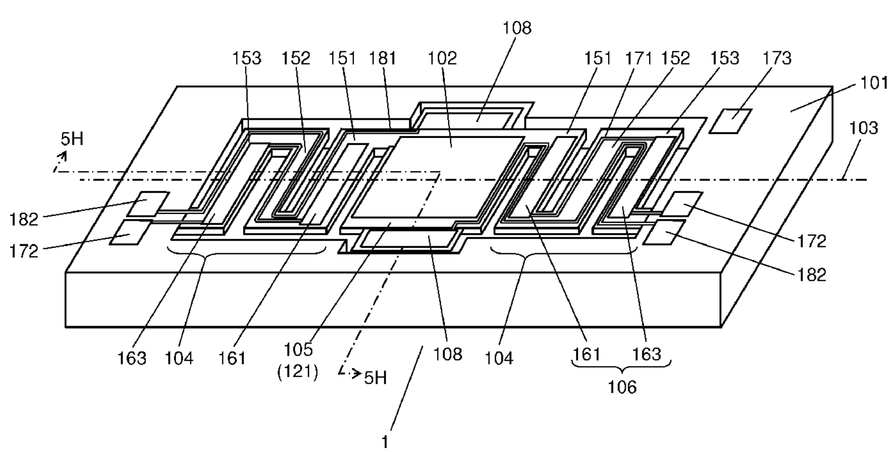

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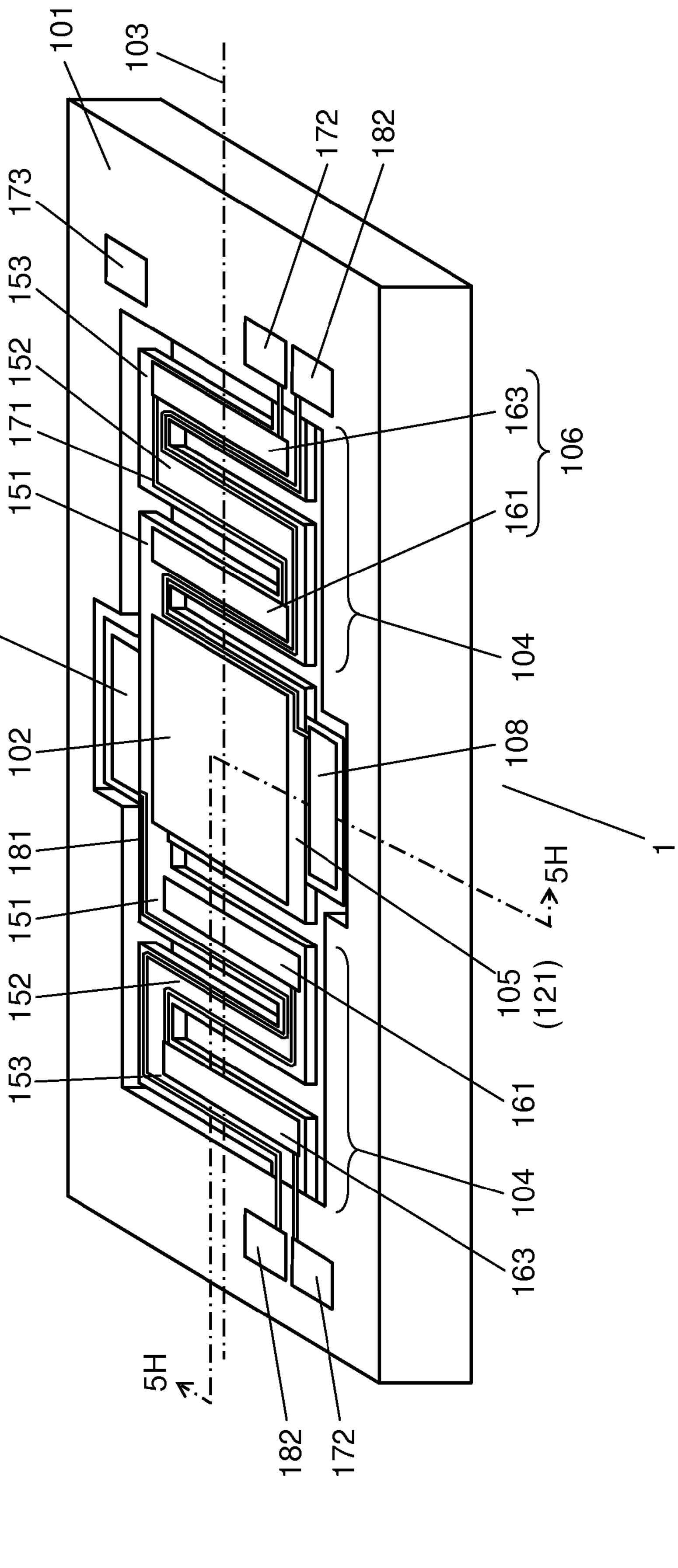
FIG. 1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(121)
5H
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FIG. 2A

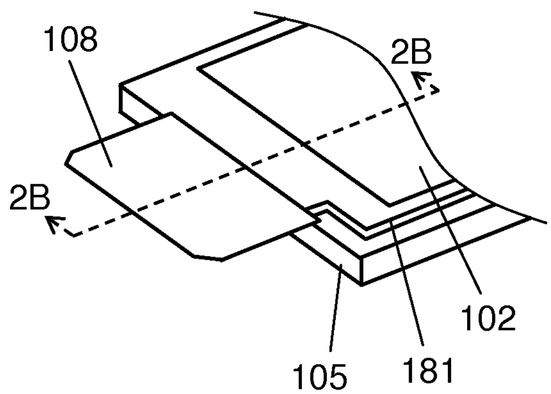

FIG. 2B

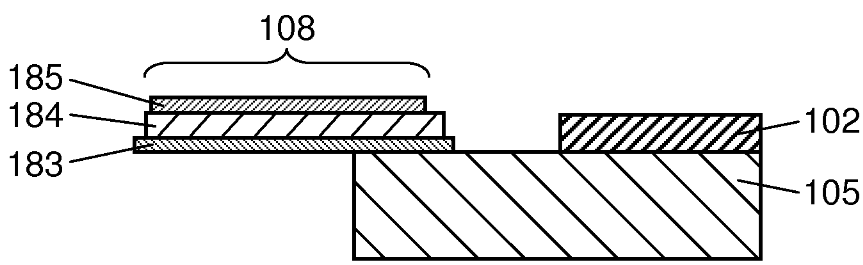

FIG. 2C

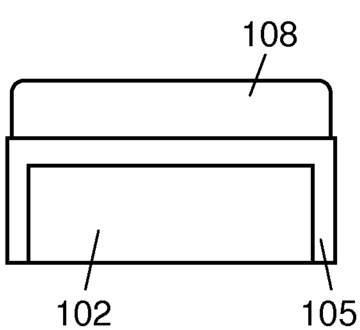

FIG. 2D

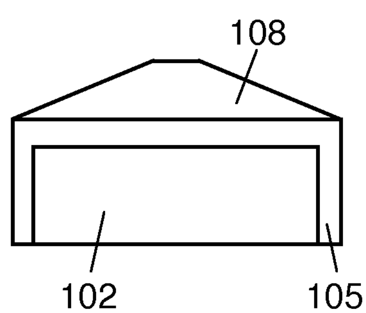

FIG. 3A

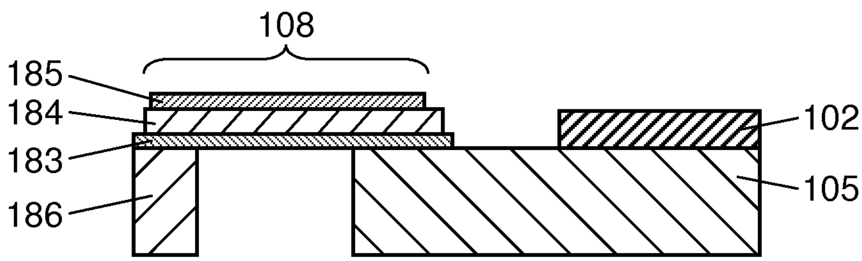

FIG. 3B

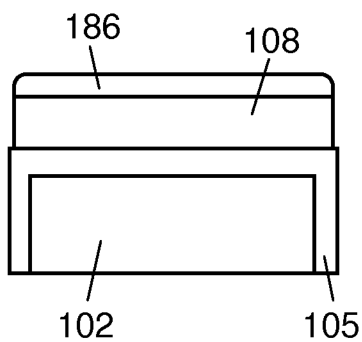

FIG. 3C

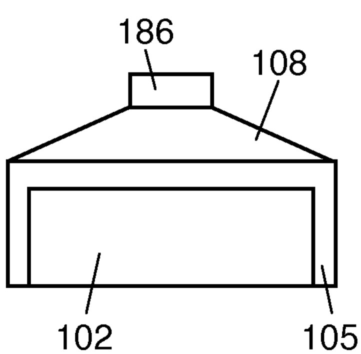

FIG. 3D

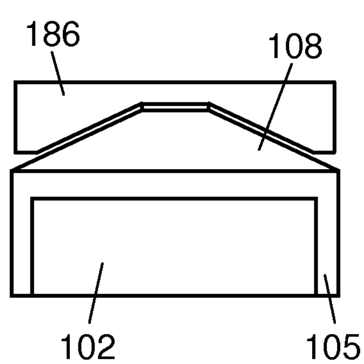

FIG. 4

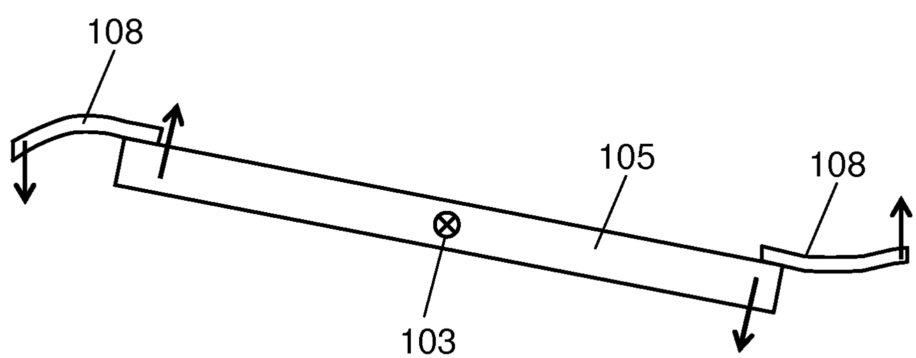

FIG. 5A

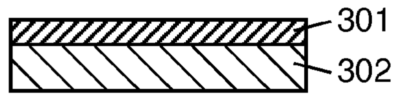

FIG. 5B

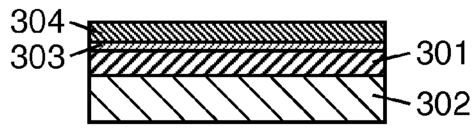

FIG. 5C

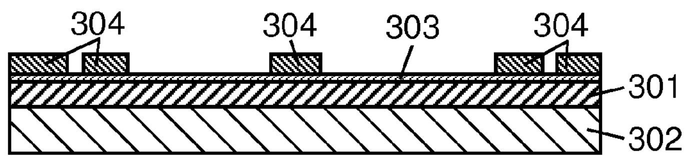

FIG. 5D

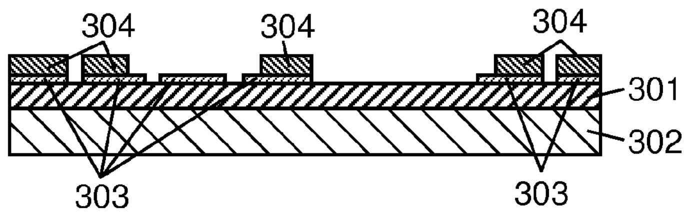

FIG. 5E

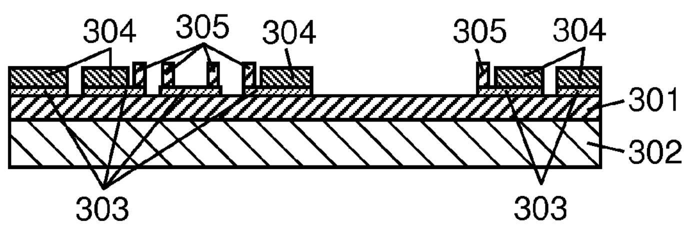

FIG. 5F

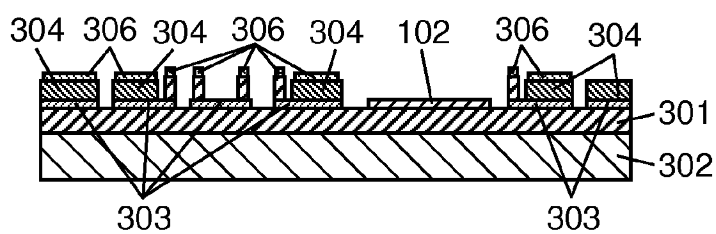

FIG. 5G

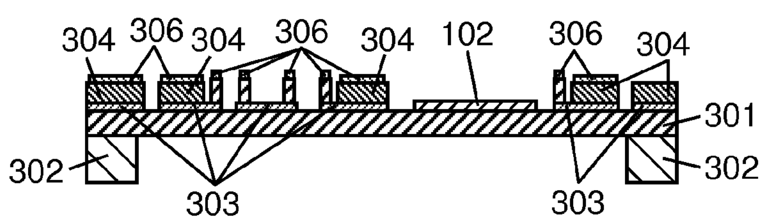

FIG. 5H

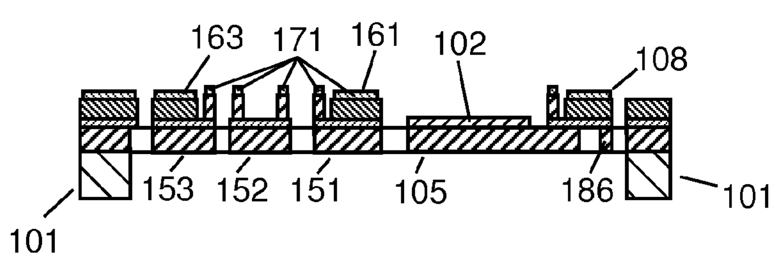

FIG. 6

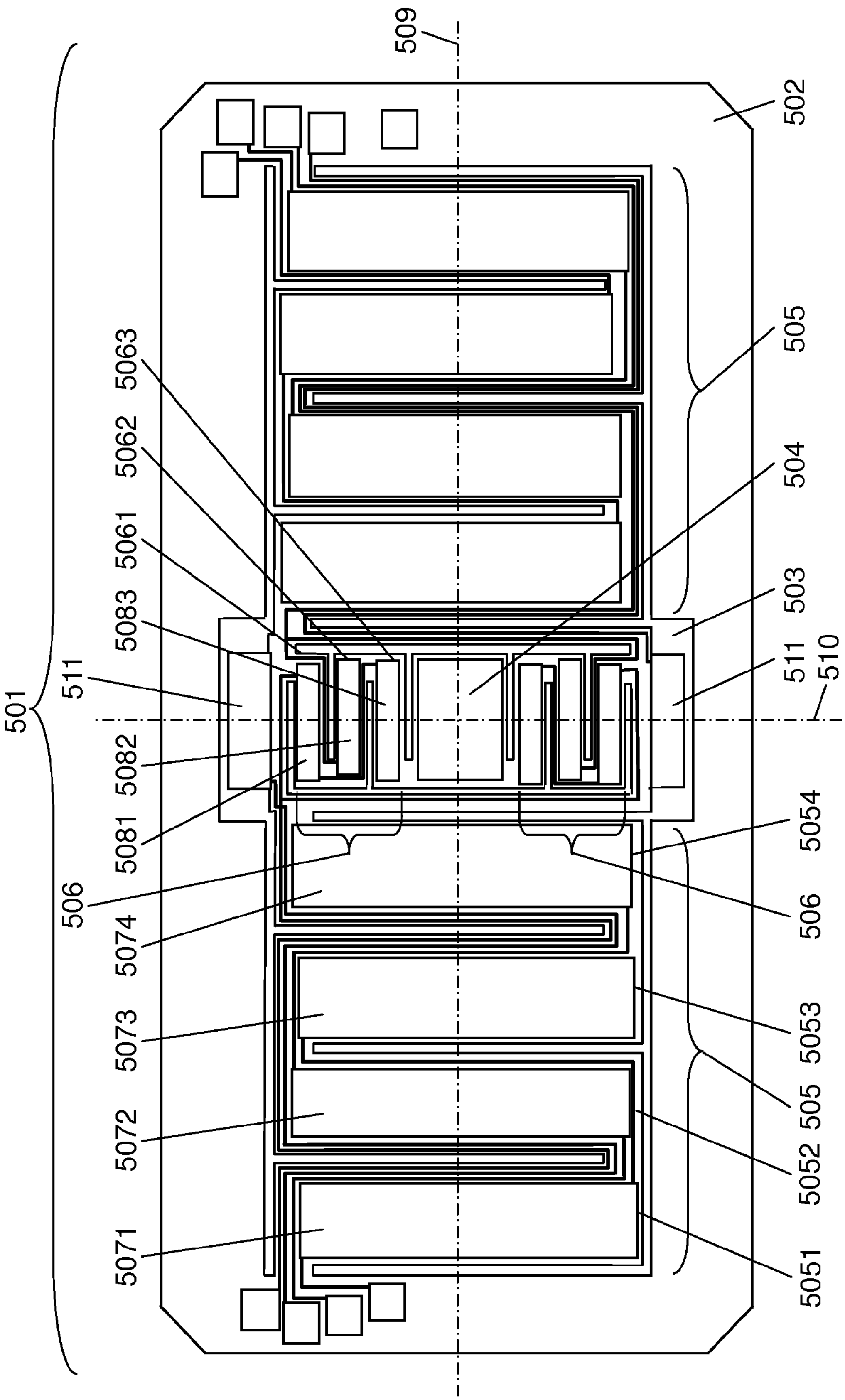
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FIG. 7

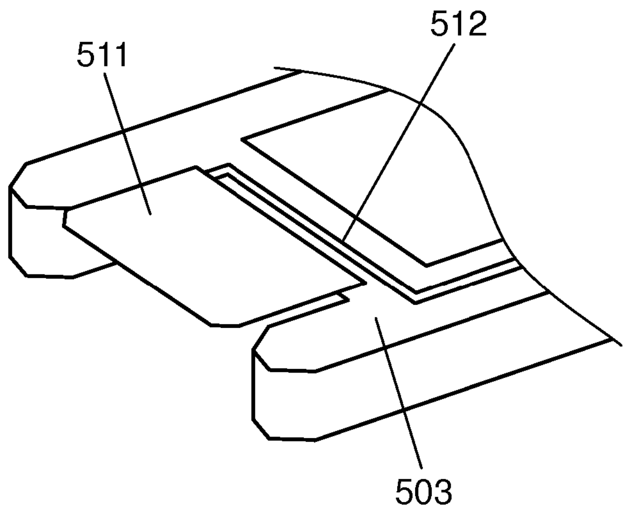
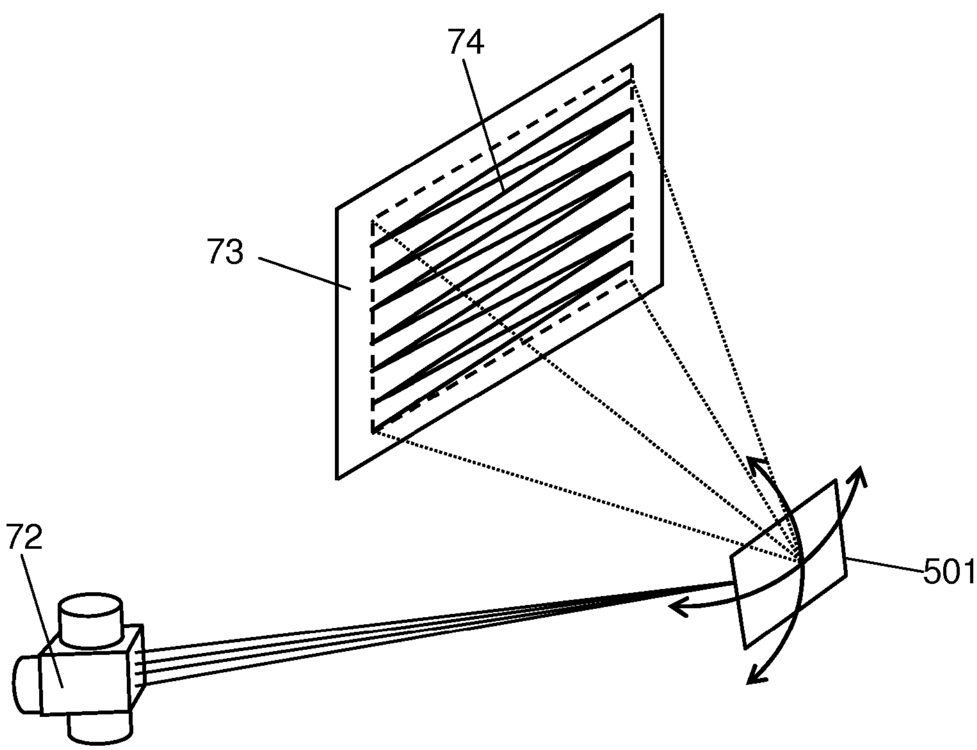


FIG. 8



OPTICAL REFLECTING ELEMENT AND ACTUATOR

This application is a national phase of International Application No. PCT/JP2013/001554, filed on Mar. 11, 2013, which in turn claims the benefit of Japanese Application No. 2012-058287, filed on Mar. 15, 2012, the disclosures of which Applications are incorporated by reference herein.

TECHNICAL FIELD

The present invention relates to an optical reflecting device for use in a laser printer, a bar-code reader, or an image projection device such as a head-up display or a head-mounted display. The present invention also relates to an actuator having a similar structure to the optical reflecting device.

BACKGROUND ART

Optical scanners, which scan a light flux emitted from a light source such as a laser or a light-emitting diode, are used in practical applications. These optical scanners are classified into a one-dimensional scanning type such as a laser printer or a bar-code reader, and a two-dimensional scanning type such as an in-car radar or a projection display device. For these optical scanners, it is important to detect the position of the mirror surface, and hence, various efforts have been made to provide a monitoring function for achieving this detection.

For example, Patent Literature 1 discloses a method of detecting the position of the mirror surface by providing a light receiving element outside the device, and making the light receiving element receive the light reflected from the device.

Patent Literature 2 discloses a method of detecting the position of the mirror surface by providing a monitoring element such as a piezoresistive element or a piezoelectric element at a position where torsion or bending occurs when the mirror surface is driven.

Patent Literature 3 discloses an invention for detecting the rotation state of the mirror part by providing a piezoelectric sensor connected to the mirror part and to the torsion bar for rotating the mirror part. Patent Literature 4 discloses an invention including a piezoelectric sensor disposed outside the outer periphery of the mirror via a slit in order to solve the problem of Patent Literature 3.

CITATION LIST

Patent Literatures

Patent Literature 1: Japanese Unexamined Patent Publication No. 2009-93120

Patent Literature 2: Japanese Unexamined Patent Publication No. 2009-77595

Patent Literature 3: Japanese Unexamined Patent Publication No. 2009-169325

Patent Literature 4: Japanese Unexamined Patent Publication No. 2011-150055

SUMMARY OF THE INVENTION

An object of the present invention is to provide an optical reflecting device that directly detects the motion of the mirror surface without reducing the drive efficiency of the mirror and that has a monitoring structure with a high degree of design

freedom, imposing no restrictions on the method of connecting the mirror part and the support body.

The optical reflecting device of the present invention includes a movable plate having a reflecting surface, a first support portion, a first drive part, a first frame, and a monitor part for detecting the rotation of the movable plate. The first support portion is connected to the movable plate. The first drive part is provided on the first support portion and capable of rotating the movable plate about a first axis. The movable plate and the first support portion are located in the first frame, and the first frame is connected to the first support portion. The monitor part extends from a portion, which is most distant from the first axis, of the outer periphery of the movable plate.

In this configuration, the monitor part is deformed by the inertia force generated when the movable plate rotates. In other words, the optical reflecting device itself has a monitoring function, allowing the display system to be small. Furthermore, since the monitor part is deformed by the inertia force generated by the motion of the reflecting surface, the motion of the reflecting surface can be detected directly. The monitor part is provided in a region other than the region where the monitor part is deformed by the rotation. This suppresses a decrease in the drive efficiency and reduces power consumption. Furthermore, since the monitor part is connected only to the portion, which is most distant from the rotation axis, of the mirror part, no restrictions are imposed on the method of connecting the mirror part and the fixed frame. As a result, the optical reflecting device has a high degree of design freedom.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a perspective view of an optical reflecting device according to a first exemplary embodiment of the present invention.

FIG. **2**A is a perspective view of a monitor part of the optical reflecting device shown in FIG. **1**.

FIG. **2**B is a sectional view of the monitor part shown in FIG. **2**A.

FIG. **2**C is a top view showing a shape of the monitor part shown in FIG. **2**A.

FIG. **2**D is a top view showing another shape of the monitor part of the optical reflecting device shown in FIG. **1**.

FIG. **3**A is a sectional view in which a weight is added to the monitor part shown in FIG. **2**A.

FIG. **3**B is a top view showing a shape of the monitor part shown in FIG. **3**A.

FIG. **3**C is a top view showing another shape of the monitor part shown in FIG. **3**A.

FIG. **3**D is a top view showing further another shape of the monitor part shown in FIG. **3**A.

FIG. **4** is a schematic diagram showing the deformation of the monitor parts of the optical reflecting device shown in FIG. **1** when the mirror part rotates.

FIG. **5**A is a schematic sectional view showing a step of fabricating the optical reflecting device shown in FIG. **1**.

FIG. **5**B is a schematic sectional view showing a step subsequent to the step of FIG. **5**A in the method of fabricating the optical reflecting device.

FIG. **5**C is a schematic sectional view showing a step subsequent to the step of FIG. **5**B in the method of fabricating the optical reflecting device.

FIG. **5**D is a schematic sectional view showing a step subsequent to the step of FIG. **5**C in the method of fabricating the optical reflecting device.

FIG. **5**E is a schematic sectional view showing a step subsequent to the step of FIG. **5**D in the method of fabricating the optical reflecting device.

FIG. **5**F is a schematic sectional view showing a step subsequent to the step of FIG. **5**E in the method of fabricating the optical reflecting device.

FIG. **5**G is a schematic sectional view showing a step subsequent to the step of FIG. **5**F in the method of fabricating the optical reflecting device.

FIG. **5**H is a schematic sectional view showing a step subsequent to the step of FIG. **5**G in the method of fabricating the optical reflecting device.

FIG. **6** is a top view of an optical reflecting device according to a second exemplary embodiment of the present invention.

FIG. **7** is a perspective view of a monitor part of the optical reflecting device shown in FIG. **6**.

FIG. **8** is a schematic diagram of a display system including the optical reflecting device shown in FIG. **7**.

DESCRIPTION OF EMBODIMENTS

Problems with the conventional techniques will now be described prior to describing the exemplary embodiments of the present invention. First, according to the monitoring method of Patent Literature 1 in which the light receiving element is provided outside, a large system is required. According to Patent Literature 2 in which the detection is performed by the monitoring element provided at the region where torsional or bending deformation occurs when the mirror surface is driven, the monitoring element may hinder the deformation thereby decreasing the drive efficiency. Moreover, since the motion of the mirror is not directly detected, the detected motion may not correspond to the motion of the mirror.

According to Patent Literature 3 in which the rotation state of the mirror part is detected by providing the piezoelectric sensor connected to the mirror part and to the torsion bar for rotating the mirror part, the stress applied to the piezoelectric sensor is low, thereby generating a low signal. According to Patent Literature 4 in which the piezoelectric sensor is provided outside the outer periphery of the mirror via a slit, the device needs to be of large size because the piezoelectric sensor is disposed outside the outer periphery of the mirror. Furthermore, in the configurations of Patent Literatures 3 and 4, the piezoelectric sensor is coupled to the support portion which connects the mirror and the support body. This decreases the degree of design freedom of the part that connects the mirror and the support body.

First Exemplary Embodiment

An optical reflecting device according to a first exemplary embodiment of the present invention will now be described with reference to drawings. FIG. **1** is a perspective view of optical reflecting device **1** according to the present exemplary embodiment.

Optical reflecting device **1** includes movable plate **105**, support portions **104** as first support portions, drive parts **106** as first drive parts, fixed frame **101**, and monitor part **108** for detecting the rotation of movable plate **105**. Movable plate **105**, which is disposed in fixed frame **101**, includes reflecting surface **121** on which mirror part **102** is formed. Support portions **104** are also disposed in fixed frame **101**, and are connected to movable plate **105**. First drive parts **106** are provided on support portions **104** so as to rotate movable plate **105** about rotation axis **103** as a first axis. Fixed frame **101** as a first frame, is connected to support portions **104**. In other words, fixed frame **101** and movable plate **105** are coupled to each other via the pair of support portions **104** in a manner that movable plate **105** can rotate about rotation axis **103**. Movable plate **105** is rotated about rotation axis **103** by drive parts **106** disposed in optical reflecting device **1**.

Monitor part **108** extends from a portion, which is most distant from rotation axis **103**, of the outer periphery of movable plate **105**. More specifically, monitor part **108** is formed at an end away from rotation axis **103**. Monitor part **108** is deformed in accordance with the rotation of movable plate **105** about rotation axis **103**. By detecting the deformation, monitor part **108** can detect the drive state of movable plate **105** (mirror part **102**).

Each of support portions **104** has a meandering shape in which vibrating beams **151-153** are connected together in an accordion fold. Vibrating beams **151-153** are made of silicon.

Each of drive parts **106** is formed of drivers **161** and **163**. Driver **161** is formed on vibrating beam **151**, whereas driver **163** is formed on vibrating beam **153**. Drivers **161** and **163** each include a piezoelectric body, and upper and lower electrodes (not shown) respectively formed on and under the piezoelectric body.

The upper electrodes of drivers **161** and **163** are coupled to each other via wiring electrode **171** and are connected to driving electrode pad **172**. The lower electrodes of drivers **161** and **163** are coupled to each other via wiring electrode **171** and are connected to lower electrode pad **173**. In wiring electrode **171**, when necessary, the upper and lower electrodes are isolated from each other via an insulating layer. Applying a voltage to the piezoelectric body through driving electrode pad **172** and lower electrode pad **173** bends and deforms vibrating beams **151** and **153**. The bending and deformation allows movable plate **105** to rotate about rotation axis **103**.

It is possible to perform resonant driving by making the frequency of the voltage applied to drive parts **106** coincide with the frequency of the natural vibration mode in which movable plate **105** is rotated about rotation axis **103**. This allows movable plate **105** to rotate at a large angle even when a low voltage is applied.

Monitor part **108** will now be described with reference to FIGS. **2**A to **2**D. FIG. **2**A is a perspective view of monitor part **108**, and FIG. **2**B is a sectional view taken along line **2**B-**2**B. FIGS. **2**C and **2**D are top views showing variation of the shapes of monitor part **108**.

Movable plate **105** and support portions **104** are made, for example, of 100 μm-thick silicon. Monitor part **108** includes lower electrode **183**, upper electrode **185**, and piezoelectric body **184** interposed between these electrodes. These components together form a laminated structure. Lower electrode **183** is made, for example, of 370 nm-thick platinum. Piezoelectric body **184** is made, for example, of 3 μm-thick lead zirconate titanate (PZT). Upper electrode **185** is made, for example, of 300 nm-thick gold.

Monitor part **108** is subjected to inertia force generated when movable plate **105** rotates about rotation axis **103**. Monitor part **108**, which is much thinner than movable plate **105**, deforms easily and strains under the inertia force. The strain distorts piezoelectric body **184**, thereby generating an electrical signal. The generated electrical signal can be taken out through monitor electrode pad **182** connected to monitor wiring **181**. As a result, the motion of mirror part **102** (movable plate **105**) can be detected.

In this configuration, the mass of monitor part **108** is much smaller than the total mass of drivers **161**, **163** and mirror part **102**. This allows the detection of the rotation of mirror part **102** with hardly any influence on properties to rotate mirror part **102**, such as resonance frequency. In addition, since the inertia force is the force applied according to the acceleration of an object, that is, the motion of mirror part **102**, the motion of mirror part **102** itself can also be detected.

Monitor part **108** can be disposed not on a structural element to rotate movable plate **105**, such as vibrating beams **151-153** or drivers **161** and **163**, but on movable plate **105**. This allows monitor part **108** to be disposed without reducing the drive efficiency, so that movable plate **105** can be rotated at a desired angle only by the application of a low voltage. As a result, optical reflecting device **1** requires low power consumption.

As shown in FIG. **2**C, monitor part **108** can be formed by simply disposing a monitoring element made of a laminated thin film of rectangular shape at an edge of mirror part **102**. Alternatively, as shown in FIG. **2**D, monitor part **108** can be formed in the shape of a trapezoid or triangle having a narrow width in the direction of projecting from movable plate **105**. In this case, the stress applied to the base of monitor part **108** can be efficiently changed into an electrical signal, while reducing the size of monitor part **108**.

Furthermore, as shown in FIG. **3**A, it is possible to attach weight **186** made of silicon to the edge of the monitoring element formed of the laminated thin film composing monitor part **108**. FIG. **3**A is a sectional view of the configuration which includes weight **186**. This configuration allows the application of a larger inertia force, thereby providing a larger monitor signal.

FIGS. **3**B-**3**D are top views showing examples of the shape of monitor part **108** to which weight **186** is added. In the configuration shown in FIG. **3**B, weight **186** is attached to the edge of monitor part **108** shown in FIG. **2**C. In the configuration shown in FIG. **3**C, weight **186** is attached to the edge of monitor part **108** shown in FIG. **2**D. In the configuration shown in FIG. **3**D, weight **186** is attached along the edge and oblique sides of monitor part **108** shown in FIG. **2**D. As weight **186** increases, the inertia force increases, which preferably increases the monitor signal.

In order to detect the motion of movable plate **105** including mirror part **102** more accurately, a plurality of monitor parts **108** may be disposed symmetrical to each other with respect to rotation axis **103** if necessary. FIG. **4** shows the deformation of monitor parts **108** when movable plate **105** rotates. The plurality of monitor parts **108**, which are disposed symmetrical to each other with respect to rotation axis **103**, deform symmetrically in response to the rotation of movable plate **105**. Therefore, by reversing the phase of the signal from one of monitor parts **108** and adding the signals together, noise, etc can be reduced. This allows more accurate detection of the driving of mirror part **102**.

The inertia force detected by monitor parts **108** increases with increasing deflection angle of movable plate **105**. Therefore, the deflection angle of mirror part **102** can be controlled by performing feedback control with a signal capable of being detected by monitor parts **108**.

A method of fabricating optical reflecting device **1** including a piezoelectric actuator composed of a lower electrode, a piezoelectric body, and an upper electrode will now be described with reference to FIGS. **5**A to **5**H. FIG. **5**H is a schematic sectional view taken along line **5**H-**5**H of FIG. **1**.

As shown in FIG. **5**A, an SOI (silicon on insulator) substrate is prepared which includes active layer **301** and BOX layer (buried oxide layer) **302**. The thickness of active layer **301** equals to the thickness of the vibrating beams. Therefore, it is necessary that, in the prepared substrate, active layer **301** has a thickness corresponding to the thickness of desired drive parts. In the present exemplary embodiment, active layer **301** of the prepared SOI substrate has a thickness of, for example, 100 μm.

Next, a silicon oxide film as an insulating film (not shown) is formed on active layer **301** of the SOI substrate. Then, lower electrode **303** is formed on the silicon oxide film by a thin film process such as sputtering or deposition as shown in FIG. **5**B. After this, a layer of piezoelectric body **304** is formed on lower electrode **303** by, for example, sputtering. It is preferable that an orientation control layer (not shown) made of an oxide dielectric containing lead and titanium be formed between piezoelectric body **304** and lower electrode **303**. It is more preferable that the orientation control layer be made of lead titanate added with lanthanum and magnesium (PLMT). This improves the polarization characteristics of piezoelectric body **304**, thereby allowing the piezoelectric actuator to have high piezoelectric properties.

Next, as shown in FIG. **5**C, piezoelectric body **304** is patterned by photolithography and etching. Then, as shown in FIG. **5**D, lower electrode **303** is patterned by photolithography and etching. The etching used for lower electrode **303** and piezoelectric body **304** can be dry etching, wet etching, or a combination thereof. The dry etching is performed using, for example, fluorocarbon-based etching gas or SF_6 gas. Alternatively, piezoelectric body **304** can be wet-etched using a mixed solution of fluorinated acid, nitric acid, acetic acid, and hydrogen peroxide, and then patterned. Then, lower electrode **303** can be dry-etched and patterned.

Next, as shown in FIG. **5**E, insulating layer **305** is formed in a region where wiring electrode **171** shown in FIG. **1** is to be formed. Insulating layer **305** may be formed by preparing an insulating film by CVD or sputtering, and then patterning the film by photolithography and etching. Alternatively, insulating layer **305** may be formed by patterning a permanent resist by photolithography.

Next, as shown in FIG. **5**F, titanium-gold layer **306**, which is to be either the upper electrode or its wiring, is formed. In titanium-gold layer **306**, the titanium film under the gold film is formed to increase the adhesion with piezoelectric body **304** made, for example, of a PZT thin film. The titanium can be replaced by other metals such as chromium to increase the adhesion between piezoelectric body **304** and the upper electrode. Between the titanium film and the gold film, there is provided a firm diffusion layer, thereby allowing the piezoelectric actuator to have high adhesive strength.

Titanium-gold layer **306** including the upper electrode is patterned also by photolithography and etching. The etchant used for titanium-gold layer **306** can be a mixture of an iodine-potassium iodide solution and an ammonium hydroxide-hydrogen peroxide solution.

As one example, lower electrode **303** is made of 370 nm-thick platinum; piezoelectric body **304** is 3 μm thick; and in titanium-gold layer **306** composing the upper electrode, the titanium part is 10 nm thick, and the gold part is 300 nm thick.

If necessary, mirror part **102** is provided with a metal thin film as an optical reflection film made of silver or aluminum having excellent optical reflection characteristics. The metal thin film is patterned by photolithography and etching. The metal thin film may be formed only on necessary regions using a metal mask or the like.

Next, as shown in FIG. **5**G, BOX layer **302**, which is the base of the SOI substrate, is etched from the rear side by photolithography and etching except for the region that is to be fixed frame **101**. BOX layer **302** can be etched by, for example, wet etching. However, when it is desired to process vertically so as to achieve a fine structure, BOX layer **302** can be etched by alternately applying SF_6 gas and C_4F_8 gas, which suppresses etching.

Finally, as shown in FIG. **5**H, active layer **301** of the SOI substrate is patterned again from the rear side by photolithography, and then etched except for vibrating beams **151-153**, which are to be support portions **104**, and movable plate **105**. Removing those regions of active layer **301** which are to be monitor parts **108** allows monitor parts **108** to have a thin-film structure composed of piezoelectric body **304**, the upper electrode, and the lower electrode **303**. If necessary, the region of active layer **301** which corresponds to weight **186** may be left. In the photolithography in this case, a resist can be uniformly formed and patterned by, for example, spray coating also on the substrate having a step portion formed at the first rear-side processing.

Through the above-described procedure, optical reflecting device **1** shown in FIG. **1** is completed.

Support portions **104** each have a meandering structure in the present exemplary embodiment, but may alternatively have a torsion beam structure. Monitor parts **108** include piezoelectric body **304** in order to detect the degree of deformation, but may alternatively include an element that changes an electrical signal according to the degree of deformation, such as a strain resistance element. Monitor parts **108** can detect the state of rotation of movable plate **105** without depending on the configuration of support portions **104** or drivers **161** and **163**. In other words, monitor parts **108** do not detect the degree of deformation of support portions **104** or drivers **161** and **163**. Therefore, the state of rotation of movable plate **105** (mirror part **102**) can be detected without decreasing the drive efficiency. As a result, optical reflecting device **1** has low power consumption.

Second Exemplary Embodiment

An optical reflecting device according to a second exemplary embodiment of the present invention will now be described with reference to FIG. **6**. FIG. **6** is a top view of optical reflecting device **501** according to the present exemplary embodiment.

Optical reflecting device **501** includes fixed frame **502** as a first frame, movable frame **503** as a second frame disposed in fixed frame **502**, and mirror part **504** disposed in movable frame **503**. Mirror part **504** and movable frame **503** are held by a pair of second support portions **506** so that mirror part **504** can rotate about second rotation axis **510**. Fixed frame **502** and movable frame **503**, on the other hand, are held by a pair of first support portions **505** so that movable frame **503** can rotate about first rotation axis **509**.

Each of first support portions **505** has a meandering structure in which four vibrating beams **5051-5054** are connected together in an accordion fold. Vibrating beams **5051-5054** are made of silicon and first drivers **5071-5074** are provided thereon, respectively. Each of first drivers **5071-5074** forming a first drive part has a laminated structure formed of a piezoelectric body, an upper electrode, and a lower electrode (none shown). Applying a voltage to each piezoelectric body bends and deforms vibrating beams **5051-5054** so as to rotate movable frame **503** about first rotation axis **509**.

The rotation angle of movable frame **503** can be increased by reversing the phases of two adjacent ones of first drivers **5071-5074** to each other. More specifically, first drivers **5071** and **5073** may be supplied with electrical signals in-phase with each other, and first drivers **5072** and **5074** may be supplied with electrical signals in-phase with each other. The electrical signals to be applied to first drivers **5071** and **5073** may be different in phase by 180 degrees from those to be applied to first drivers **5072** and **5074**.

Each of second support portions **506** also has a meandering structure in which three vibrating beams **5061-5063** are connected together in an accordion fold. Vibrating beams **5061-5063** are made of silicon and second drivers **5081-5083** are provided thereon, respectively. Each of second drivers **5081-5083** forming a second drive part has a laminated structure formed of a piezoelectric body, an upper electrode, and a lower electrode (none shown). Applying a voltage to each piezoelectric body bends and deforms vibrating beams **5061-5063** so as to rotate mirror part **504** about second rotation axis **510**.

Thus, in the present exemplary embodiment, mirror part **504**, second support portions **506**, second drivers **5081-5083**, and movable frame **503** as the second frame together correspond to movable plate **105** of the first exemplary embodiment. Second support portions **506** are connected to mirror part **504**. Second drivers **5081-5083** are provided on second support portions **506** so that mirror part **504** can rotate about second rotation axis **510**, which is substantially orthogonal to first rotation axis **509**. Inside movable frame **503**, mirror part **504** and second support portions **506** is located and movable frame **503** is connected at its inside to second support portions **506** and is connected at its outside to first support portions **505**.

The rotation angle of mirror part **504** can be increased by reversing the phases of the voltages of adjacent ones of the beams to each other. More specifically, second driver **5081** and **5083** may be supplied with electrical signals in-phase with each other, whereas second driver **5082** may be supplied with an electrical signal different in phase by 180 degrees from those to be applied to second drivers **5081** and **5083**.

In optical reflecting device **501** used for projecting images, it is required to rotate mirror part **504** about second rotation axis **510** at a comparatively high driving frequency of 10 kHz or more. Therefore, it is common to use resonance. In this case, second drivers **5081** and **5083** are provided, but second driver **5082** is not provided. Second drivers **5081** and **5083** are supplied with electrical signals of the same frequency as that in the natural vibration mode in which mirror part **504** rotates about second rotation axis **510**. This configuration allows resonant driving, thereby largely rotating mirror part **504**.

Monitor part **511** is disposed at an end of movable frame **503**. The end is distant from first rotation axis **509**. FIG. **7** is an enlarged perspective view of a region where monitor part **511** is disposed. Movable frame **503** is formed of a 300 μm-thick silicon substrate, and surrounds mirror part **504**. Similar to monitor part **108** of the first exemplary embodiment, monitor part **511** has a laminated structure formed of a lower electrode, a piezoelectric body, and an upper electrode.

Monitor part **511** is deformed and strained by the inertia force generated when movable frame **503** rotates about first rotation axis **509**. As a result, the piezoelectric body of monitor part **511** is strained, thereby generating an electrical signal. The generated electrical signal can be taken out through wiring portion **512**. Wiring portion **512** includes an insulating layer to prevent short circuits between the upper and lower electrodes from occurring. Since the inertia force is applied according to the acceleration of an object, that is, the motion of movable frame **503**, it is possible to take out an electrical signal corresponding to the motion of movable frame **503**. The above-described structure and configuration are similar to those of the first exemplary embodiment.

When movable frame **503** rotates, monitor part **511** deforms according to the inertia force. Therefore, it is preferable that monitor part **511** be as far away from first rotation axis **509** as possible. If a pair of monitor parts **511** are disposed symmetrical to each other with respect to the rotation axis, they will deform symmetrically. By reversing the phase of the signal from one of the pair of monitor parts **511** and adding the signals together, noise, etc. can be reduced, thereby allowing more accurate detection of the motion of movable frame **503**.

When optical reflecting device **501** rotatable in two axial directions is used for display, it is often the case that a low frequency of 15 to 60 Hz is used for low-speed rotation (driving) about first rotation axis **509**, and that non-resonant driving is performed using a saw-tooth wave drive signal. In order to detect the motion of movable frame **503**, it is possible to dispose the monitor part in, for example, first drivers **5071-5074**, which cause deformation to rotate movable frame **503**. In the case of resonant driving, the motion of movable frame **503** can be detected by providing the monitor part in a part of the portions that cause deformation.

In the case of non-resonant driving, on the other hand, it is necessary to provide a monitor part in each of the portions that cause deformation. Therefore, when each of first support portions **505** has a meandering structure, monitor parts are required to be disposed in vibrating beams **5051-5054**, respectively. An increase in the total area of the monitor parts, however, decreases the area of first drivers **5071-5074**, and hence decreases the drive efficiency.

Monitor parts **511**, on the other hand, extend from those portions, which are most distant from first rotation axis **509**, of the outer periphery of movable frame **503** as components of the movable plate. This allows the motion of movable frame **503** to be detected directly while maintaining the area of the drive parts and the drive efficiency even at the non-resonant driving.

Note here that each of first support portion **505** and second support portion **506** has a meandering shape in the present exemplary embodiment, but may alternatively has a torsion beam structure. Monitor parts **511** can detect the rotation of movable frame **503** without depending on the configuration of first drivers **5071-5074** or second drivers **5081-5083**. In addition, monitor parts **511** do not detect the degree of deformation of first drivers **5071-5074**, second drivers **5081-5083**, first support portions **505**, or second support portions **506**. Therefore, monitor parts **511** can detect the rotation of movable frame **503** without decreasing the drive efficiency, thereby contributing to a reduction in the power consumption of optical reflecting device **501**.

FIG. **8** shows a laser scanning display system including optical reflecting device **501**. The light emitted from light source **72** is reflected by mirror part **504** of optical reflecting device **501** and projected on screen **73**. Rotating mirror part **504** about two orthogonal axes allows the laser beam to be scanned on screen **73**. The output of light source **72** can be modulated in accordance with the position of mirror part **504** (that is, the position of the laser beam on screen **73**) so as to obtain desired image **74**. In this case, the position of mirror part **504** can be detected using the electrical signal detected by monitor parts **511**.

If no reflecting surface is provided on movable plate **105** or mirror part **504**, the configuration described in the first or second exemplary embodiment may be used as an actuator.

INDUSTRIAL APPLICABILITY

The optical reflecting device of the present invention has a monitoring function for detecting the drive state of the mirror part without reducing the drive efficiency. Therefore, the optical reflecting device performs high precision control while driving the mirror with low power consumption. Thus, the optical reflecting device can be used in an image projection device or an optical scanner such as a head-up display, a head-mounted display, and a laser printer.

The invention claimed is:

1. An optical reflecting device comprising:
a movable plate having a reflecting surface;
a first support portion connected to the movable plate;
a first drive part provided on the first support portion and capable of rotating the movable plate about a first axis;
a first frame connected to the first support portion and containing the movable plate and the first support portion; and
a monitor part capable of detecting rotation of the movable plate,
wherein the monitor part is disposed on the movable plate such that the monitor part is movable with movement of the movable plate,
the monitor part is disposed on an outer periphery of the movable plate and extends outwardly from the movable plate in a direction heading away from the first axis, and
the outer periphery is the most distant portion of the movable plate from the first axis.

2. The optical reflecting device according to claim **1**, wherein the movable plate includes:
a mirror part;
a second support portion connected to the mirror part;
a second drive part provided on the second support portion and rotating the mirror part about a second axis substantially orthogonal to the first axis; and
a second frame containing the mirror part and the second support portion and being connected to the second support portion at an inside of the second frame and connected to the first support portion at an outside of the second frame.

3. The optical reflecting device according to claim **2**, wherein each of the first and second support portions has a meandering shape.

4. The optical reflecting device according to claim **1**, wherein the first support portion has a meandering shape.

5. The optical reflecting device according to claim **1**, wherein the monitor part includes a lower electrode, an upper electrode, and a piezoelectric body interposed between the lower electrode and the upper electrode.

6. The optical reflecting device according to claim **1**, wherein the monitor part is a strain resistance element.

7. The optical reflecting device according to claim **1**, wherein the monitor part extends along the outer periphery in a direction parallel to the first axis.

8. The optical reflecting device according to claim 1, wherein the monitor part is disposed on a top surface of the movable plate.

9. An actuator comprising:
a movable plate;
a first support portion connected to the movable plate;
a first drive part provided on the first support portion and capable of rotating the movable plate about a first axis;
a first frame connected to the first support portion; and
a monitor part capable of detecting rotation of the movable plate,
wherein the monitor part is disposed on the movable plate such that the monitor part is movable with movement of the movable plate,
the monitor part is disposed on an outer periphery of the movable plate and extends outwardly from the movable plate in a direction heading away from the first axis, and
the outer periphery is the most distant portion of the movable plate from the first axis.

10. The actuator according to claim **9**, wherein the monitor part includes a lower electrode, an upper electrode, and a piezoelectric body interposed between the lower electrode and the upper electrode.

11. The actuator according to claim **9**, wherein the monitor part is a strain resistance element.

12. The actuator according to claim **9**, wherein the monitor part extends along the outer periphery in a direction parallel to the first axis.

13. The actuator according to claim **9**, wherein the monitor part is disposed on a top surface of the movable plate.

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